# Hydroelectricity – An answer to energy needs

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***Topic:***
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***Issue 2.1 : Energy resources and technologies, today and tomorrow***
***Issue 2.5 :Renewable and alternative energies in the global energy mix***

## 0 – Executive Summary

At the onset of the 21st century, the world energy sector has to face major challenges. The growing of population and development of non OECD countries require that they develop their energy production capacity at a strong pace whilst at the same time governments have to tackle the global warming issue. Finally and concomitantly the scarcity of fossil fuels threatens future energy availability.

We show in the paper that hydroelectricity is an answer that could reconcile these antagonistic challenges. There are large unexploited resources in most developing economies (BRIC, Africa, Asia). Whilst Europe and North America have equipped a part of their natural sites, there is still room for capacity increases by exploiting hydro potential, and by for example equipping multi purpose dams not equipped for electricity production.

Thanks to the constant increase in technology performance, retrofitting the European and American hydropower plants ageing fleet would allow to increase the efficiency of the plant (sometimes by more than 5%) and minimise the unavailability due to failure. In some cases it would also allow to increase the output of the plant and therefore increase the peak power capacity of the country and total energy production.

Finally the fast development of power production from renewables such as wind or solar increases the grid management complexity due to the intermittency and non fully accurate predictability of these energy sources. By their storage and fast power adaptation capacities Hydro Power Plants and Hydro Pumped Storage plants are the perfect solution to tackle those issues. Pumped Storage plants also offer the possibility to increase hydro potential where all potential natural resources have been equipped. Furthermore it provides the unique advantage to be able to store the excess energy produced by the other renewables (night production for instance) to make it available during peak periods when most needed by the grid. Finally we present the variable speed technology, the latest major innovation in hydro electricity that further increases the flexibility and adaptability of Pumped Storage Plants.

## I – Key Energy challenges

The events of the first decade of the 21st century are already making the 20th century look far away. Urbanisation and demographic growth continue apace. The dynamic economies of non-OECD countries are pulling millions out of absolute poverty whilst shifting the world's centre of economic gravity eastwards. Not only the BRIC countries, but also some of the more recently identified 'Next 11'[1] countries (Bangladesh, Egypt, Indonesia, Iran, Korea, Mexico, Nigeria, Pakistan, Philippines, Turkey & Vietnam) , are expected to overtake certain G7 economies in absolute GDP terms in the next 40 years, bringing appreciable gains in health, education and material wealth. Unlike the 20th century, this welcome development risks being undermined by concerns over the finite resources of the Earth and its ability to withstand unprecedented levels of human activity. Access to energy and electricity are central to this important debate and, as will be demonstrated below, renewable hydro-electric energy has a significant role to play in reconciling what could be otherwise conflicting needs.

The latest forecasts by the International Energy Agency[2] and the U.S. Energy Information Administration[3] expect that electricity's share in the world's total energy demand will grow strongly throughout the period 2006-2030 : an average annual increase of 2.4[3] to 2.5%[2] trending well above the increase in the world's primary energy demand of 1.5%[2] p.a. This latter increase of 1.5% per year leads to an overall absolute increase in energy demand of 40%[2] over the period, whilst electricity generation is predicted to increase by 77%[3]. The movements in the world economic and demographic landscape are also contributing to a change in the geographical mix of electricity production and consumption : in the next few years the non-OECD countries are expected to definitively overtake the OECD countries in terms of generation[3], whilst the UN's latest population report[4] forecasts significant population growth being in currently less developed regions. The world population in 2050 is estimated to be 8.9 billion people, or at least within a band of 7.4 to 10.6 billion depending on the different hypotheses employed.

Access to electricity is considered a gauge of development contributing to human well-being. One-fifth of the world's current population is still without access to electricity[2], even on an intermittent basis. The forecast increases in electrical generation are expected to reduce the numbers of those still deprived of electricity, though the amount will not disappear completely, nor be spread equitably amongst different parts of the world.

Adequate electricity supplies are also important for urbanisation and continued economic growth. It is clear why increasing generation capacity and network coverage are therefore important projects for many countries, driving their economic growth and social policies. Governments nevertheless know that these projects have to be seen within a wider context.

Energy security is a major preoccupation. Stocks of fossil fuels by their nature are condemned to decrease in quantity and increase in price. Securing access to them can involve negotiations not only with suppliers but also with transit countries, as well as earning the hard currencies necessary to buy them on the world market. Poor, land-locked countries in particular are vulnerable.

As governments and individuals the world over are starting to realise, even a relatively high level of energy security can be rendered meaningless if the Earth's equilibrium itself becomes unbalanced by human activity : pollution and global warming. As the World Energy Outlook acknowledges, the burden of providing the increase in energy required in their Reference Scenario will be shouldered by fossil fuels : coal, gas and oil[2]. Use of coal and gas is driven by electricity generation. Efforts to reduce emissions have started and will continue, notably by promoting sources of renewable energy. Indeed, renewable energies are expected to be the fastest growing source of electricity generation in the period 2006-2030. The annual growth rate of 2.9% naturally leads to a share of 21% in the 2030 energy mix, compared to 19% today[3], with vigorous growth expected from wind power and hydro-electric power (33% and 54% respectively of the estimated capacity additions of renewables until 2030[3]). Indeed, these two forms of renewable energy are closely tied together, as will be explored below, as the storage capability of hydro-electricity is an effective foil to the intrinsic unpredictability of wind power generation.

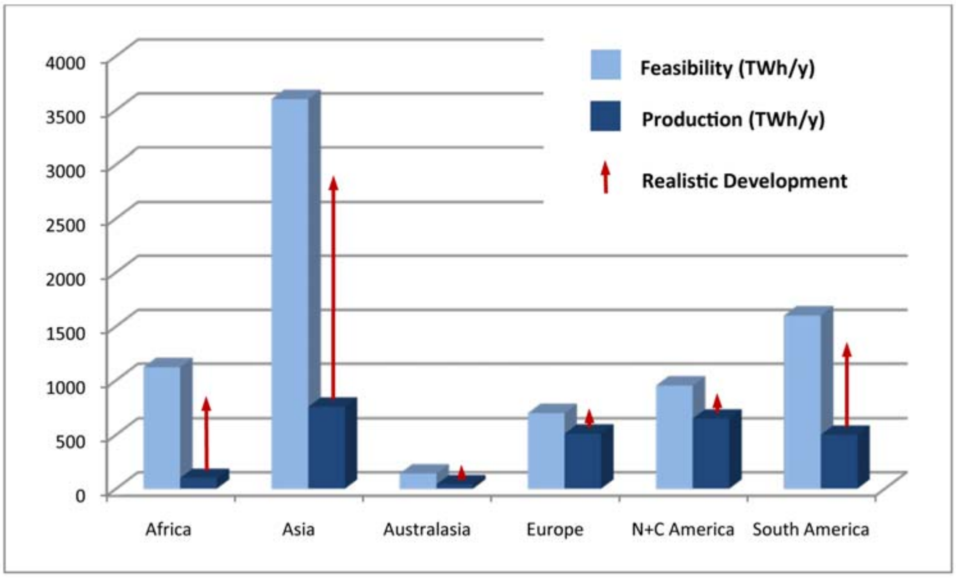
It may appear that nations are in front of an impossible dilemma : how to generate more electricity to drive development and well-being, whilst at the same time reduce energy dependency on others, decrease pollution and emissions and favour the latest sources of renewable energy ? A key element to overcoming this dilemma lies in the strengths of a proven ally of development : hydro-electricity.

## II – New Hydro-Electric Power Plants

Hydro-electricity uses the water cycle and as such can be considered a renewable resource. Today, 88% of the 19% of renewables in the energy mix comes from hydro-electricity[3]. Hydro-electricity is therefore already an important source of clean energy in the struggle against climate change.

Generating efficiency, at above 90%, is the highest of all sources of energy and improvements continue to be made in this area. In order to neutralise seasonal fluctuations or prediction difficulties in certain cases, water power learned a long time ago how to integrate storage methods and the potential energy stored today in reservoirs represents the world's largest and cheapest form of energy storage. This storage is likely to be critical for those countries seeking to integrate more recent renewable energies such as wind and solar, which, by their nature, are intermittent and not always easy to predict. Water is also a natural resource. Many of the world's poorest or developing countries have significant water resources which can be used to bring energy independence and development. Water management implies not just electricity generation, but also flood control, irrigation and storage of drinking water. 1.1 billion people are still estimated to be without adequate water supplies[5]. Finally, there are still significant 'reserves' of hydropower : figure 1 shows how much potential still exists : the distribution of technically feasible production, as well as existing production, are of particular interest.

*Figure 1* : Estimated Hydropower development by region
*Source : International Hydropower Association, 2007*




**a – Significant resources for hydro projects**

Much of the current and future growth of China, India, Brazil and Russia will be driven by hydro-electricity : based on 2005 statistics[7], before the spike in oil prices, these countries alone account for 51% of the world's estimated reserves of both technically feasible and economically viable hydropower generation. In 2005, none of the above was using more than 20% of their identified economically feasible potential, despite the substantial efforts which have already been made and which continue to be made. Some of the most notable projects which are underway are the 6300 MW Longtan, 6000 MW Xiangjiaba and 4800 MW Jinping 2 complexes in China, the 6476 MW Rio Madeira projects in Brazil and the 2000 MW Lower Subansiri project in India (*Figure 2*).

*Figure 2* : Construction of the Lower Subansiri Power House, 2009

The importance of these projects and others like them, should not be under-estimated : it is predicted that in 2030, China and India alone will account for 28% of the world's total energy consumption.

Another area of high growth in energy consumption is in the ASEAN countries, which, with the exception of Indonesia, are not well endowed with fossil fuels. The ASEAN members of the 'Next Eleven' countries, Vietnam, Indonesia and the Philippines, have hydropower resources. The Philippines are judged to have harnessed much of their economically feasible hydro-power base : Vietnam, with about 1% of the world's identified economically feasible resources, is making large strides : a recent example being the 2400 MW Son La project. Indonesia has significant unexploited potential. Hydropower can therefore satisfy some of the growing energy needs of these countries at the point of consumption, as well as in certain cases being a precious source of additional income if surplus electricity can be exported to neighbours.

This same logic can also apply to countries such as Nepal, Bhutan and Tajikistan in the Himalayas, as well as to Central Africa. It is estimated that the Inga projects on the River Congo (4320 MW Inga 3 and 40000 MW Grand Inga) could provide electricity to 0.5 billion Africans who are currently without it. At the moment, the population of Africans without electricity is expected to increase over the period 2006-2030, especially in Sub-Saharan Africa. Recent examples of significant hydro-electric development in Africa are Merowe in Sudan (1250 MW), Bujagali in Uganda (250 MW) and Bui in Ghana (400 MW).

*Figure 3* :
Cahora Bassa,
Mozambique,
1245 MW

Hydropower potential therefore exists in areas where economic and social development are expected and desired in the next decades.

This encouraging conclusion should not exclude OECD countries from the picture. Major schemes are underway, some examples being Peribonka (390 MW), the projects of Lower Churchill River (2260 MW) and Romaine River (1550 MW) in Canada, and the Illisu (1200 MW) project in Turkey.

The additional benefits of hydropower are also being harnessed in innovative and complimentary ways as increasing the density or coverage of hydropower production also has significant advantages.

### b – Hydro, complimentary schemes to cover from national to local energy needs

Hydroelectricity is available within various complimentary schemes : reservoir, run-of-river, pump storage plant, large, medium, small. Each scheme brings additional advantages to make hydroelectricity into a complete renewable energy solution.

National grid daily issues require mass production of energy with a short time capability to answer to daily fluctuations. Large and medium scale hydroelectric plants bring the only renewable answer to such concerns, with an ability to cover base load and peak load demands.

To tackle difficulties of supply for remote areas, small and medium scale projects with connection to local distribution system bring the most benefits : lower investment, shorter time to commissioning, low operation and maintenance, no transmission losses. However, for isolated networks, the frequency regulation is a major challenge, due to isolation from the national grid.

Tomorrow, local networks will include a large proportion of ‘distributed variable energy resources’ (DVER) : wind, solar, biomass, fuel cell. The load management and frequency regulation of such networks cannot be handled in the traditional way by bulk centralised energy generation through the high voltage transmission line. Decentralised hydro schemes are an answer to support DVER penetration at local level.

Hydro plants are the only means of renewable energy production to secure national, local and isolated networks as well as coping with intensive penetration of DVER.

### c – Existing multipurpose dams, an unexploited potential

Worldwide, there are today a huge number of large dams. The International Commission of Large Dams (ICOLD) has registered at the end of 2007, the number of 33112 dams. The uses of these dams are various : flood control, hydroelectricity, water supply, irrigation, recreation, navigation, fish breeding. Most of them are multipurpose, but not all of them have hydroelectric equipment.

On a worldwide basis, only the dams with more than 1 billion of m3 can be considered as well equipped, but still more than 18% are not equipped (*see table 1*). For the capacities below, the ratio of non-equipment is increasing until more than 87%, when reservoirs are between 1 and 5 million m3.

*Table 1* :

| Capacity in millions of m3 | Nber of units | Without hydroelectric equipment | ratio in % | With hydroelectric equipment | ratio in % |
|---|---|---|---|---|---|
| 1 to 5 | 10069 | 8769 | 87,09% | 1300 | 12,91% |
| 5 to 20 | 6841 | 5032 | 73,56% | 1809 | 26,44% |
| 20 to 50 | 2844 | 1750 | 61,53% | 1094 | 38,47% |
| 50 to 100 | 1630 | 940 | 57,67% | 690 | 42,33% |
| 100 to 1000 | 2745 | 1329 | 48,42% | 1416 | 51,58% |
| > 1000 | 1004 | 183 | 18,23% | 821 | 81,77% |

*Source : ICOLD – registered dams list*

As an example, Europe has build hydroelectric equipment for many years, but there are still some huge reservoirs without hydroelectric equipment. The segment of reservoirs from 100 to 1000 billion m3 is only equipped with hydroelectricity at a rate of 77%. (*see table 2*).

*Table 2* :

| Capacity in millions of m3 | Nber of units | Without hydroelectric equipment | ratio in % | With hydroelectric equipment | ratio in % |
|---|---|---|---|---|---|
| 1 to 5 | 4366 | 1046 | 23,96% | 3320 | 76,04% |
| 5 to 20 | 2814 | 591 | 21,00% | 2223 | 79,00% |
| 20 to 50 | 1669 | 307 | 18,39% | 1362 | 81,61% |
| 50 to 100 | 1045 | 140 | 13,40% | 905 | 86,60% |
| 100 to 1000 | 669 | 153 | 22,87% | 516 | 77,13% |
| > 1000 | 112 | 9 | 8,04% | 103 | 91,96% |

*Source : ICOLD – registered dams list*

These facts are showing a clear unexploited potential on existing dams for hydroelectricity, all around the world. Existing dams are less costly to upgrade to accommodate hydroelectric equipment than full new projects. Even if irrigation and water supply will request special features of the hydroelectric equipment and special designs to avoid pollution, lack of pressure, sediment transport in the distributing pipes and so on.
Many examples of multipurpose dams are already existing and integrate hydroelectricity as a functionality, in addition to irrigation and/or water supply and/or flood control. The multipurpose approach, which features adapted hydroelectric equipment (Small Hydro, Large Hydro, Pump Storage Plant), must become the concept which maximises water resources.

## III – Rehabilitation of Existing Plants

### a – Rehabilitation, a great opportunity for improving energy production

Hydroelectric power plants have a lifetime, which will be determined by several characteristics like operating modes, the “starts and stops” per day, the number of production hours per year, the quality of water, the type of technologies and quality of the main equipments, the quality of the erection and the quality and frequency of the maintenance. The consensus today is to consider that the expected lifetime of a hydroelectric power plant is between 40 and 50 years.

Ageing hydroelectric power plants are featuring :

- Low rate of availability (loss of production)
- Low reliability to answer to grid requests (high number of unplanned outages and failed starts)
- Low global performances due to use of old technologies and design
- Decreasing performances due to ageing process
- Increase of maintenance and operating costs

After 40 years of production, refurbishment or upgrading are justified and become a great opportunity for improving energy production of ageing hydroelectric power plants. Power plant rehabilitation programs can cover three main areas: (*see figure 4*)

- Firstly, refurbishment programs involve the rehabilitation of facilities with the objective of optimising the layout of the power plant, restoring initial performance levels and extending its service life through the refurbishment of key equipment (including the turbine runner).

- Secondly, it involves upgrading equipment by taking into account the latest technology evolutions leading to overall improved performance levels (efficiency, output).

- Thirdly, it can involve automation of the old and obsolete control system, guaranteeing a level of reliability equivalent of a new power plant.

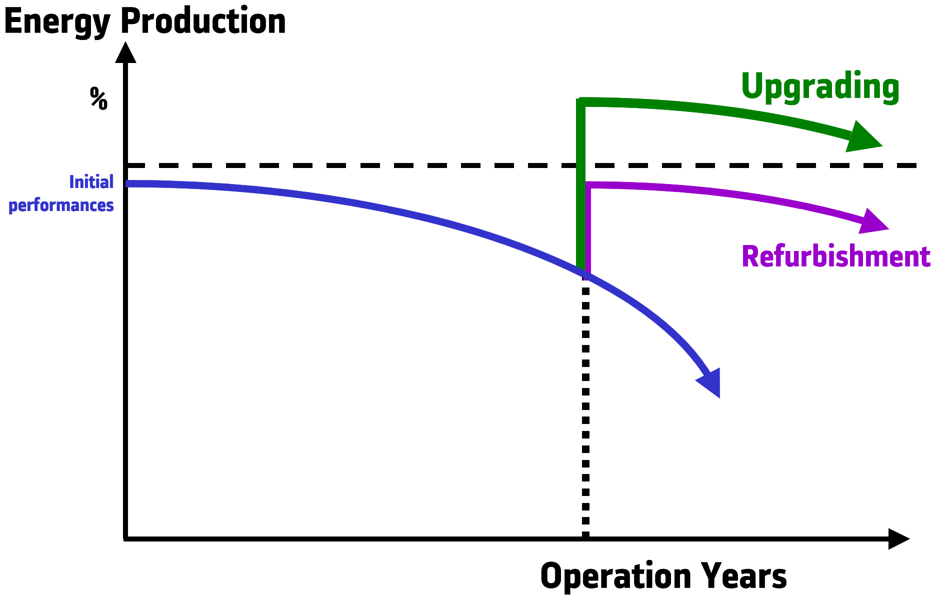



*Figure 4*

Last, but not least, the existence of the plant structure makes rehabilitation programs attractive due to:

- Short “time to market” : the downtime due to refurbishment or uprating works are shorter than any new project. In addition, methodologies exist to optimise works duration in regards of the reduction of loss of production. As an example, to go from a “cost” approach to a “short outage” approach to minimise overall cost, may be a key added value for some projects.

- No additional environmental impact : reutilisation of existing structures.

**b – Upgrading, an effective approach for matching power needs**

Special concern has to be given to the “Upgrading” choice, which is an unique opportunity for improving energy production to match new and future energy needs by using latest technology evolutions such as CFD calculations (Computerized Fluid Dynamics), flux calculations, finite element analysis, new materials with higher electrical and mechanical characteristics, electronic regulation, “oil free” concepts, etc ... Economically, the increased performance will generate more revenues and shorten Return On Investment. Technically, there are 2 types of improvement of

Hydro Power Plant (HPP) performance level, which lead to more power generation and/or more peak capability :

1. Improvement of the global performance of the HPP : more annual generation of MWh with the same volume of water and the same operating scheme, thanks to an increase in the global efficiency of equipment. *(figure 5)*

2. Improvement of peak capability of the HPP : more MWh, but during a shorter time, thanks to an increase of the maximum output in using higher discharge. Increase of MWh annual generation is also possible if the unit is mainly operated close to maximum output, due to higher efficiency in this operating range. *(figure 6)*

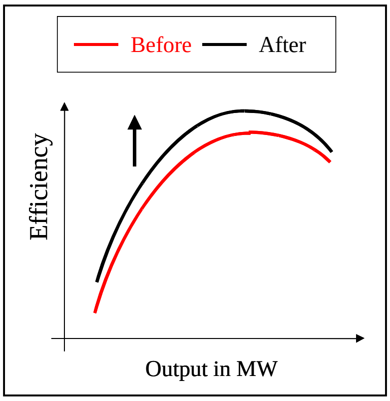



*Figure 5*

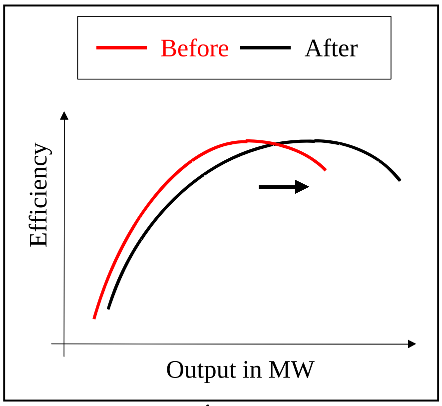



*Figure 6*

All existing HPPs have room for efficiency improvement (case 1). The level of efficiency gain is directly linked to the age of the HPP and the available technology and knowledge utilized for the initial design, when the HPP was built. Due to the fact that the maximum discharge is not increased, there is no major impact for such improvement on the water passage equipment like penstocks or valves. Due to the fact, that each HPP is unique (site, discharge, head) and was built with tailor-made equipment, the efficiency improvement analysis requires a specific study for each case. Expected efficiency improvement can be up to 5%.

Output improvement (case 2) will generate more impacts on all the existing equipment of the HPP, due to the increase of the maximal discharge. In addition to the need of electro-mechanical equipment able to produce more MW, the water passage equipments have to be correctly sized to accept higher discharge (penstocks, valves, concrete structure). The feasibility analysis for such an approach must be global and includes all the equipment of the water passage from intake to draft tube. Due to the fact that each site is unique (discharge, head), a specific study is mandatory to size out potential improvement. Expected Output improvement can be up to 30%

In most cases, output improvements can be combined to efficiency improvements to reach an optimized scheme.

### c – Existing fleet, a high potential for increasing renewable energy production

In 2009, the worldwide hydroelectric power plant fleet was estimated at 887 GW during the international conference HYDRO 2009 in Lyon, France. Almost 30% of these plants (263GW) are more than 40 years old. (*see figure 7*).

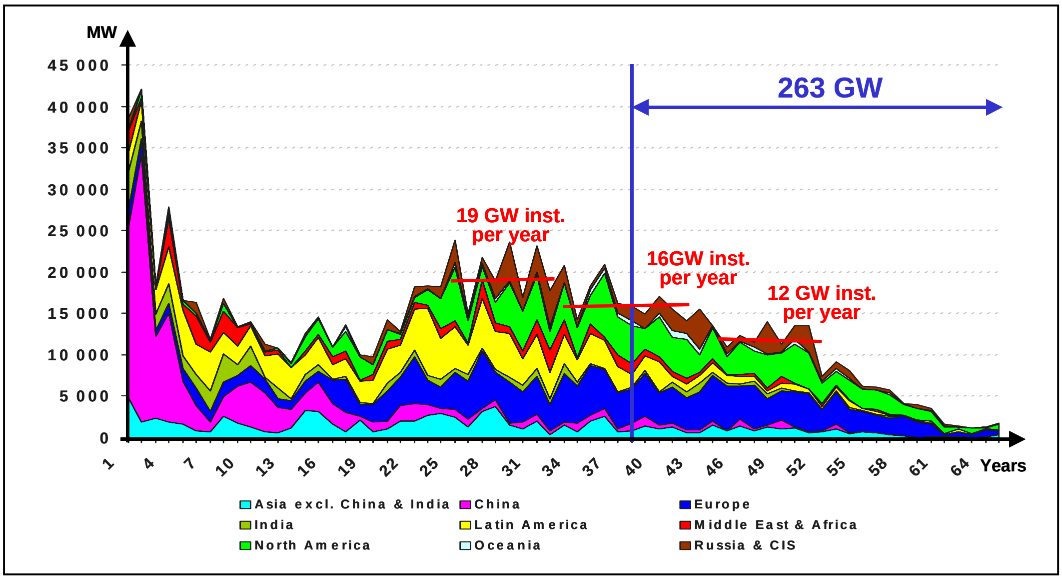



*Figure 7*

Europe (205GW total fleet) and North America (160GW total fleet) are concentrating the biggest part of "more than 40 years old" plants : 64% of the world fleet. Europe's ageing hydropower plant fleet reaches 37% of the total installed base. For North America, the "ageing" ratio is reaching 43%. (*figure 8*)

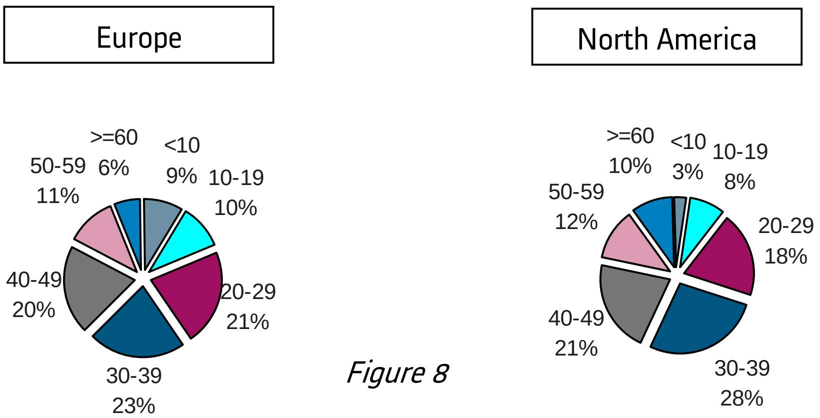



*Figure 8*

The rehabilitation market level was not and is not in line with ageing process of the plants :

- The past rhythm of rehabilitation of "ageing" plant was known as low.
- The actual rhythm of rehabilitation (turbine + generator) is growing and can be estimated around 10GW per year, but actual ageing process results in 16GW each year reaching 40 years old. This figure will grow to 19GW per year from 2015 to 2025.

The “10GW” rhythm is not sufficient to avoid to have an increase of the average age of the fleet. It is mandatory to go to 30 GW per year to face the coming wave and to stop the ageing process of the today old fleet to avoid dramatic incidents.

For energy production in Europe and North America, this situation is an opportunity to answer to energy needs such as predictability, availability and renewable. For each additional 20GW upgraded per year and for each 5% of increase of performance, rehabilitation programs will create 1000MW of renewable and predictable energy, available within few minutes to face grid requirements.

## IV – Integrating Intermittent Renewable Energy

Growing energy needs, rising fuel prices, concerns over energy security and the threat of global warming are pushing governments and energy companies to develop cleaner power sources. Besides hydro development, in 2008 alone, 8,484 MW of wind capacity were installed in Europe. If the EU is to meet its commitments to cut $CO_2$ emissions, member states will have to install an estimated additional 390 GW of hydro capacity by 2020, while the European Wind Energy Association’s (EWEA) target for total wind installations by 2020 is 180 GW. Wind energy production is also in fast progression in North America and in Asia where the Chinese government plans to develop 150 GW of Wind generation.

Unlike thermal (coal, oil, gas or nuclear power) or hydro, the amount of energy produced by solar and wind power is by nature intermittent and not accurately predictable, which increases the grid management complexity. To make mixed fuel portfolios with renewable energies lucrative, companies are therefore looking to develop renewable storage technologies that can ensure the production of enough capacity to meet peak demand while ensuring enough flexibility to offer short-term grid balancing and complete renewable cycle. Energy storage allows operators to adapt production to consumption, thereby increasing efficiency and optimally balancing the grid. With global wind capacity growing at a staggering rate of 50% per year and solar energy capacity gaining ground, utilities are using hydro storage to capture energy from variable sources and manage it optimally.

Of all the renewable energy sources, indeed only hydropower offers a storage opportunity. It is therefore playing an increasingly crucial role in balancing the variations in production and consumption levels of other renewable energy sources by storing their excess energy. Yet the development of large-scale renewable portfolios will depend on a successful and lucrative integration of large amounts of variable energy, while ensuring grid stability. To address this, many companies are expanding their hydroelectric capacity.

### a - Hydro Pumped Storage, the solution to renewable energy intermittency

While hydroelectric global resources are by nature limited to the inflow of water in the upper reservoir Pumped Storage Plants (PSP) allows to overcome this limitation. Pumped storage is the most efficient and flexible large-scale means of storing energy available today, far beyond compressed air, lithium ion and other storage technologies commonly used. This proven technology is helping utilities to efficiently balance the grid and to develop their renewable energy portfolios. Pumped storage is therefore set to play a key role in enabling countries to meet their ambitious targets to cut greenhouse gas emissions and to build additional clean, renewable energy capacity.

Pumped storage turbines pump water into an upper reservoir and store it when demand is low. When demand and prices peak, the water is released through turbines to a lower reservoir and the electricity is sold at premium prices. This allows utilities to reap financial benefits from the storing of intermittent renewable energy, which might otherwise be lost. Up to 80% of the energy consumed during the overall cycle is recovered, which can be sold when demand peaks.

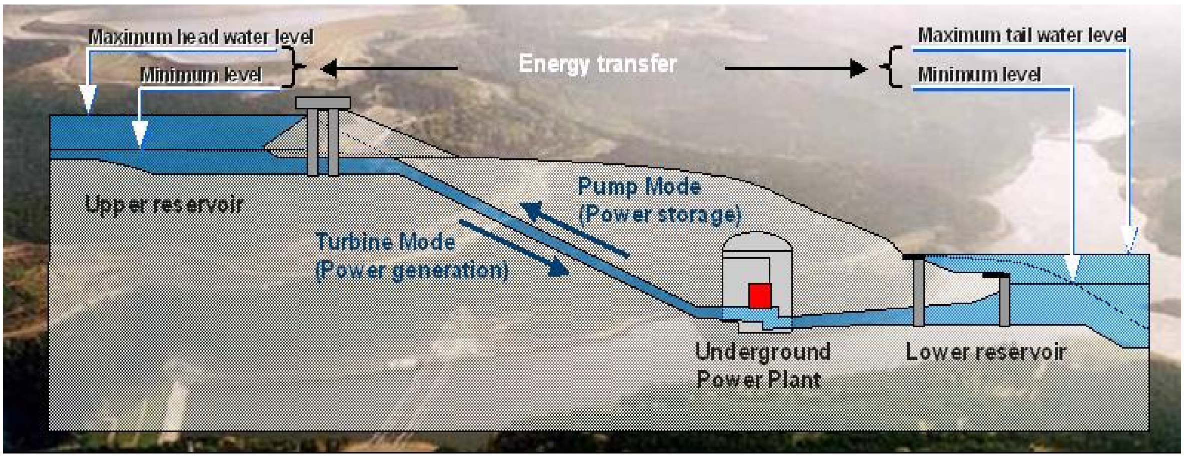



*Figure 9: Pumped storage power plant schematic*

This technology can ramp up to full production capacity within minutes providing a quick response for peak-load energy supply and making it a useful tool to balance the grid during unplanned outages of other power plants. In November 2006, 20 million European households were left in the dark following a power outage. Alpine dams were able to supply about 5 million homes with 5000 MW within 20 minutes, and the variable pumped storage dam of Grand'Maison (Isère, France) accounted from 10 to 20% of this energy supply. The technology also enables utilities to operate their other energy sources at their most efficient levels, enabling fossil-fired and renewable energy sources to be run optimally.

There is over 127 GW of pumped storage in operation worldwide. In response to the grid flexibility needs in Europe, North America and Asia, the pumped storage market is expected to grow 60% over the next four years, with an average of 6 GW of added pumped storage capacity to be ordered each year. We expect 50% of the market to come from China. In Europe, which accounts for approximately 26% of the market, opportunities are mostly focused around the alpine regions (Switzerland, Austria, Germany), Spain and Portugal. In the USA, where 45 plants currently in operation totalise 20,720 MW capacity, an additional 43 plants corresponding to 36,600 MW are currently in the licensing process.

### b – Variable speed technology, latest innovation to further increase flexibility

Variable Speed is the latest major innovation in hydroelectricity. These machines have the capability to regulate their power both in pumping and production mode thanks to their capability to adapt their rotational speed whilst conventional machines can only regulate their power in production mode.

This means the variable speed plant owner can adjust the level of power needed when pumping at night or when there is a light load, which in turn means that conventional thermal power plants that are operated for frequency adjustment can be stopped. This helps utilities operate their fleets more economically while reducing CO2 emissions. Finally, the technology also allows utilities to earn revenues from balancing the network's frequency (ancillary services).

The variable speed element of the turbines and generators enables utilities to match supply to demand to the minute, pumping when demand marginally drops, and releasing when demand marginally rises. This helps them reach maximum efficiency of their fuel portfolios and maximise revenues. It also means load balancing can be achieved using a clean, renewable energy source.

This increased flexibility is particularly useful when PSP are used to balance the intermittent production from renewables. This production has to be balanced at all times of the day, which includes the night hours used by PSP to pump up the water in the upper reservoir. Variable speed machines can achieve this operation and provide balancing service in the same time.

## V – Conclusion

The energy challenges of the next 30 years appear daunting and, in certain cases, in conflict with one another. Their complexity is such that one solution alone cannot provide a full answer. It is nevertheless equally clear that hydro-electricity, being renewable, proven, highly efficient, storable and with still very significant resource potential, possesses a unique combination of attributes which will aid decision-makers to plan and execute energy development with confidence.

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